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Durability and Breakage of Feed Pellets during Repeated Elevator Handling

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Abstract. Pelleting of animal feeds is important for improved feeding efficiency and for convenience of handling. Pellet quality impacts the feeding benefits for the animals and pellet integrity during handling. To determine the effect of repeated handling on feed pellet breakage and durability, a 22.6-t (1000-bu) lot of feed pellets made from corn meal was transferred alternately between two storage bins in the USDA-ARS, Grain Marketing and Production Research Center research elevator at Manhattan, Kansas, at an average flow rate of 62.2 t/h. Samples from a diverter-type sampler were analyzed for particle size distribution (by sieving) and durability (by the tumbling box method). The apparent geometric mean diameter of samples decreased with repeated transfers, whereas the mass of accumulated broken pellets increased with repeated transfers. The percentage of broken pellets increased by an average of 4.0% with each transfer from an initial value of 17.5%, which was within the range of published values for shelled corn obtained from the same elevator. The pellet durability index averaged 92.9% (standard deviation=0.6%) and did not change significantly (p>0.05) during the transfers. The high pellet durability index indicates that the pellets can withstand repeated transfers in feed handling systems.

Keywords. durability, breakage, elevator handling, feed pellet, pellet durability index, dust, broken pellets, particle sizing.

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Introduction

Pelleting of animal feed is important for improved efficiency in animal feeding and for convenience in feed handling. Research has shown that animals fed with good-quality pellets have better growth performance and feed conversion than those fed with mash, reground pellets, or pellets with more fines (Jensen et al., 1962; Jensen and Becker, 1965; Kertz et al., 1981; Brewer et al., 1989; and Zatari et al., 1990). Behnke (1994) indicated that improvements in animal performance have been attributed to decreased feed wastage, reduced selective feeding, decreased ingredient segregation, less time and energy expended for prehension, destruction of pathogens, thermal modification of starch and protein, and improved palatability. A significant part of the improvement is related to the quality of the pellet. Good-quality pellets are needed to withstand repeated handling processes and reduce the formation of fines by mechanical action during transport.

Gustafson (1959) classified the forces acting on the pellets as impact, compression, and shear. Impact forces shatter the pellet surface and any natural cleavage planes in the pellet. Compression forces crush the pellet and also cause failure along cleavage planes. Shear forces cause abrasion of the edges and surface of the pellet.

Young (1962) used a model handling system consisting of a bucket elevator, a hopper, and an inclined screw conveyor to measure pellet durability. Fifty pounds of pellets were continuously cycled through this system for a period of 10 min. At the end of the test, the pellets were screened and the fines were removed. The Pellet Durability Index (PDI) was calculated as the percentage of the mass of surviving pellets over the total mass of pellets.

Several laboratory methods have also been developed to measure the durability of pellets, namely: the tumbling box method, Holmen durability tester, and Stokes hardness tester. The tumbling box method is the most popular method (Winowiski, 1998) and an accepted standard in the feed industry in North America. The ASAE Standard S269.4 (ASAE Standards, 2003b) is based on the tumbling box method. The tumbling box method uses 500 g of pellets, from which the fines have been removed. The pellets are placed in a box that revolves for a period of 10 min at a speed of 100 rpm. After testing, the pellets are screened on a mechanical sieve shaker. The PDI is calculated as the mass of the pellets retained on the screen divided by the total mass of pellets. The correlation coefficients of the results from the tumbling box method and those from Young (1962) were 0.95 for pellets cooled for 24 h and 0.67 for hot pellets (ASAE Standards, 1987).

The Holmen durability tester is the most common method in Europe because it simulates the pneumatic conveyors in European feed mills (Winowiski, 1998). It is a pneumatic method of measuring the durability of the pellets. A sample size of 100 g of pellets is transported through tubes with high velocity air for 30 to 120 s, simulating the handling process. Pellets are subjected to impact and shear forces. Fracture occurs when pellets strike the right-angle corners of the tester. The PDI is calculated based on the remaining whole pellets that are collected and weighed.

The Stokes hardness tester is used for transverse compression testing. The tester consists of a calibrated spring, a cone with a tip, and a plate supporting the opposite side of the cone. The cone tip bores on the cylindrical surface of the pellet during testing. Pressure is regulated by a screw turned by hand to compress the spring. Only 10 pellets are tested, and pellet hardness is expressed in psi (Young, 1962).

A more recent method is the LignoTester developed by Borregaard Ligno Tech USA (Rothschild, WI) (Winowiski, 1998). It uses a sample of 100 g of pellets and blows them around

a perforated chamber for 30 s. Pellets come out at the end of the cycle because the fines are removed as they are generated. These remaining pellets are used to calculate the sample's PDI.

Aarseth (2004) studied the susceptibility of feed pellets for livestock to attrition during pneumatic conveying. He investigated the effects of air velocity, bend radius, and number of repeated impacts for three commercially available feeds in a 100-mm-diameter pipeline. The three commercial feeds were produced by Felleskjøpet, Kambo, Norway. Feeds 'Formel Favør 30' (FF30) and 'Formel Elite' (FE) had pellet diameter of 6 mm, and were formulated for ruminants, whereas, 'Kombi Norm' (KN) had smaller pellet diameter (3 mm) and was formulated for pigs. He used Weibull analysis to assess pellet quality. This analysis incorporates fracture mechanics with statistics in order to describe the strength of brittle materials. Brittle materials show high scatter in strength due to variation in crack or flaw sizes, called Griffith cracks. Weibull analysis considers a relationship between the scatter in fracture strength and the size distribution of Griffith cracks. Aarseth and Prestløkken (2003) demonstrated that this method can be applied to feed pellets for ruminants. Aarseth (2004) used the same method to analyze the three commercial pellets mentioned earlier.

Baker et al. (1986) found that breakage susceptibility of shelled corn increased significantly during handling in pneumatic conveying systems with approximately 100-mm-diameter pipe. Tests involved using total lengths of 31 m to 60 m, with two to four 90-degree elbows with a 1.22-m radius of curvature.

Foster and Holman (1973) studied physical damage (breakage) to corn, wheat, soybeans, and dry edible peas by commercial handling methods. Commercial handling methods included in their study were dropping products by free fall (simulating bin filling), dropping products through a spout (simulating railcar filling), grain-throwing (simulating the loading of barges and ship holds), and handling products in a bucket elevator.

Data on repeated handling of shelled corn in the USDA-ARS, Grain Marketing and Production Research Center (GMPRC) research elevator at Manhattan, Kansas, have been reported. Martin and Stephens (1977) repeatedly transferred corn alternately between two bins. Percentage of breakage of corn kernels increased linearly during the repeated-handling tests. Martin and Lai (1978) reported values of 0.080%, 0.037%, and 0.028% for fine dust (less than $125\mu\text{m}$) generated per transfer for corn, sorghum, and wheat, respectively, with a similar handling system. Converse and Eckhoff (1989) observed linear increases in broken corn and fine material (BCFM) during repeated handling of six lots of corn that had been subjected to different drying treatments. The rates of increase were generally higher for corn dried at higher temperatures. Total dust emissions per transfer varied from 0.084% to 0.21% of the total mass with the greater emissions associated with corn dried at higher temperatures.

Repeated handling in an elevator affects pellet breakage and quality. Repeated handling data of feed pellets in an elevator would be vital for feed handlers in evaluating and improving their feed handling and transportation procedures. The objective of this study was to determine the effect of repeated handling in an elevator on feed pellet quality. Measures of feed pellet quality included percentage of broken pellets, PDI, and dust generated.

Materials and Methods

Feed Materials and Test Facility

A total of 22.6 t of feed pellets were delivered by truck to the research grain elevator at the USDA-ARS, GMPRC, Manhattan, Kansas. The facility has a storage capacity of 1,935 m³

(55,000 bu). It has one receiving pit and two bucket elevator legs, each with a maximum feed rate of 81.6 t/h (3,000 bu/h). The elevator is equipped with a pneumatic dust-control system, including cyclone separators. The system was operated so that the flow rate through the upper cyclone separator was 4.9 m³/s and the flow rate through the lower cyclones was 6.8 m³/s. These settings were the typical operating conditions for the elevator.

The feed pellets were made of corn meal, with a moisture content of 13.18% wet basis (wb). The crude fat/oil, protein, and starch contents were 1.53%, 8.55%, and 65.63%, respectively. The pellets had an initial bulk density of 644 kg/m 3 , a nominal diameter of 6.40 mm, and an average pellet length of 10.5 mm (standard deviation (SD) = 1.2 mm).

The mass of feed pellets (22.6 t) was determined by weighing the truck containing the feed pellets both before and after unloading in the elevator receiving area. During unloading, samples were taken every 2.5 min with a pelican sampler. These initial samples were labeled as Transfer 0. The pellets were then moved from the receiving pit by belt conveyor and were bucket elevated to bin 1 for storage before testing.

Test Procedure

Elevator Transfers and Sampling

Figure 1 shows a schematic diagram of the pellet flow during the test. The pellets were transferred alternately between storage bin 1 (approximately 85-m³ volume and 20-m deep) and bin 2 (approximately 411-m³ volume and 26-m deep). From storage bin 1, the feed descended 3.0 m to the boot. The bucket elevator raised it 53 m, where it was discharged through a spout. It descended 3.0 m to pass through an automatic diverter-type (DT) sampler (Carter-Day Co., Minneapolis, MN). The feed then descended 1.5 m to a hopper, and then another 3.0 m to the distributor, before it descended 4.6 m to enter storage bin 2. Transfer from bin 1 to bin 2 constituted one transfer and one-half of a cycle.

From storage bin 2, pellets again descended to the boot, were elevated 53 m before they descended and passed through the DT sampler, descended again to the hopper, and then to the distributor, and finally back to storage bin 1. This second transfer completed one cycle. A total of six transfers, or three cycles, at an average flow rate of 62.2 t/h (range: 52.7 to 68.6 t/h), were done initially. Then the pellets were left in bin 1 for one week before they were again transferred to bin 2. They were left for one more week in bin 2 before they were finally transferred back to bin 1. This scenario was selected because it emulated the number and type of transfers in the typical handling process for this feed.

Each transfer was labeled serially, from Transfer 1 to Transfer 8. Samples were taken every 2.5 min during each transfer with the DT sampler. An average of 9 samples were taken during each transfer, with an average mass of 642 g (SD = 54.3 g).

Pellet samples during receiving (i.e., Transfer 0) and those from Transfers 1 to 8 were divided appropriately with a Boerner divider for sieving (100 g), tumbling box test (500 g), and moisture-content determination (25 g). The samples were placed in sealed plastic bags and stored inside sealed plastic buckets at 4°C in a refrigerated room for subsequent analysis.

Particle Sizing

The nine 100-g samples for each transfer were combined and sieved to determine the size distribution of broken material. They were sieved in accordance with ASAE Standard S319.3 (ASAE Standards, 2003b) by using a Ro-Tap RX-29 sieve shaker. The screen sizes were US Standard sieve screen size openings: 8.00 mm, 6.70 mm, 6.30 mm, 5.60 mm, 3.35

mm, 1.70 mm, 1.00 mm, and pan (<1.00 mm). Samples were initially sieved and shaken until they reached endpoint (ASAE Standards, 2003b). End-point was determined by comparing the mass on each sieve at one-minute intervals after an initial sieving time of 10 min. If the mass on the smallest sieve containing any of the pellets changed by 0.1% or less of the material mass during a one-minute period, then sieving was considered complete. In accordance with ASAE Standards S269.4 (ASAE Standards, 2003a), samples passing through the 5.60 mm-mesh sieve were considered broken pellets. Samples were weighed in a digital balance (O-Haus Adventurer Pro AV 4101, O-Haus Corp., Pine Brook, NJ) with a resolution of 0.1 g.

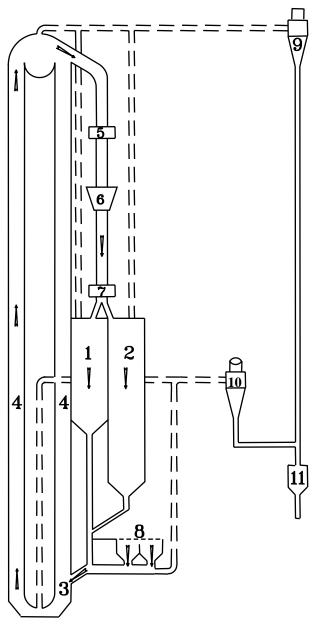


Figure 1. Schematic diagram of the USDA-ARS-GMPRC research elevator, showing the flow of the pellets and location of equipment (not drawn to scale): 1. storage bin 1, 2. storage bin 2, 3. elevator boot, 4. elevator legs, 5. diverter-type sampler, 6. hopper, 7. distributor, 8. receiving area, 9. upper cyclone, 10. lower cyclones, and 11. tailing dust bin.

The geometric mean diameter of the particles by mass, mm (GMD), geometric standard deviation by mass (GSD), and geometric standard deviation of particle diameter by mass, mm (GSD_w), were calculated using the following equations (ASAE Standards, 2003b):

$$GMD = \exp\left(\frac{\sum_{i=1}^{n} W_i \ln(\overline{d}_i)}{\sum_{i=1}^{n} W_i}\right)$$
 (1)

$$GSD = \exp\left(\sqrt{\frac{\sum_{i=1}^{n} W_{i} \left[\ln\left(\overline{d}_{i}\right) - \ln\left(GMD\right)\right]^{2}}{\sum_{i=1}^{n} W_{i}}}\right)$$
(2)

$$GSD_{w} = \frac{1}{2}GMD[GSD - GSD^{-1}]$$
(3)

where:

 d_i is the nominal sieve aperture size of the ith sieve, mm

 $d_{\it i+1}$ is the nominal sieve aperture size in sieve next larger than ith sieve (just above in a set), mm

$$\overline{d}_i = \left(d_i d_{i+1}\right)^{0.5}$$

GMD is the geometric mean diameter, mm

GSD is the geometric standard deviation by mass, dimensionless

 GSD_{w} is the geometric standard deviation of particle diameter by mass, mm

 W_i is the mass on ith sieve, g

n is the number of sieves +1 (pan)

Pellet Durability Index

The durability of the pellets was evaluated by using a durability tester and procedures following ASAE standard S269.4 (ASAE Standards, 2003a). Samples from Transfers 0 (initial), 1 (first), 4 (middle), and 7 (second to last, after 1 week) were selected for the durability test. The durability tester consisted of four 130-mm wide tumbling boxes. The device was rotated about an axis perpendicular to, and centered in, the 300-mm sides. A 230-mm-long baffle was affixed symmetrical to a diagonal of one 300 x 300 mm side inside the box.

With four tumbling boxes, four samples were tested simultaneously. Four 500-g samples from each of Transfers 0, 1, 4, and 7 were screened separately on a 5.60-mm US standard sieve. This was the sieve that was just smaller than the nominal pellet diameter (ASAE Standards, 2003a). The pellets that were retained on the sieve (i.e., greater than 5.60 mm) were tested in the tumbling box device for 10 min at 50 rpm. Immediately after tumbling, the samples

were removed and sieved with the 5.60-mm screen for approximately 30 s to remove the fines or broken pellets. The PDI was computed by using:

Pellet Durability Index =
$$\frac{mass\ of\ pellets\ retained\ on\ the\ 5.60-mm\ sieve\ after\ tumbling}{mass\ of\ pellets\ before\ tumbling}$$
 (4)

Moisture Content Determination

Moisture content of the samples was determined according to ASAE S358.2 (ASAE Standards, 2003c). A 25-g sample was taken from each refrigerated transfer sample and placed in an aluminum moisture dish that previously had been oven-dried. The moisture dish and sample were weighed and dried in an oven at 60°C for 72 h. The dried sample and moisture dish were weighed, and moisture content was computed.

Dust Sampling

Handling of the pellets generated dust. The pneumatic control system collected the dust through the cyclone and into the tailing dust bin (Fig. 1). After each transfer, the dust collected in the tailing dust bin was emptied into a plastic bag, weighed, labeled, and stored at 4°C in a refrigerated room for later analysis. Representative dust samples from the plastic bag were obtained in accordance with the ASTM Standard E-300 (ASTM Standards, 2000). Nine samples from the plastic bag from each transfer were obtained by using a grain sampling probe. The samples were sieved with US Sieve No. 120 (125 μm). Particles that passed through the 125- μm sieve were considered as fine dust (Martin and Stephens, 1977) and were weighed.

Data Analysis

The GMD, GSD, and GSD_w values for transfers from bin 1 to bin 2 (Transfers 1, 3, 5, and 7) were separated from values for transfers from bin 2 to bin 1 (Transfers 2, 4, 6, and 8), and were compared by using two-factor Analysis of Variance (ANOVA) without replication, with the GLM procedure of SAS (SAS Institute Inc., Cary, N.C.). Comparison of mean moisture content value of each transfer was done by using Scheffe's test. Comparison of mean PDI values among transfers and mean mass of fine dust values among transfers were done by using Fisher's least-squares difference (LSD). Correlation analyses among GMD, percentage of broken pellets, percentage of tailing dust, and mass of fine dust were performed by using Pearson's correlation, and test of significance of Pearson's correlation coefficient procedures in SAS with nine transfers (including Transfer 0). The percentage of tailing dust for the eight transfers in this study was compared to published data on corn (Martin and Stephens, 1977). The comparison of mean percentage of tailing dust was done by using the standard t-test procedure in SAS.

Results and Discussion

Particle Size Distribution

The initial GMD of the pellets was 5.62 mm (Table 1). The apparent GMD decreased as the number of transfer increased. From Transfers 0 to 4, GMD decreased by approximately 1.9 mm; from Transfers 4 to 8, the GMD remained relatively constant.

The two-way ANOVA indicated that means of the GMD did not differ significantly (p>0.05) during the four cycles. The GSD, a measure of the variability of the distribution, for the four cycles were also not significantly different (p>0.05). The GSD_w between transfers to bin 2 and to bin 1 were not significantly different (p>0.05). None of the means of these parameters

were significantly different at (p>0.05) for transferring in one direction (bin 1 to bin 2), compared with the other direction (bin 2 to bin 1).

Table 1. Physical characteristics of feed pellets during repeated handling.

	Apparent		Apparent	Moisture Content
Transfers	GMD, mm	GSD	GSD _w , mm	(wb), %
0	5.62	1.69	3.09	10.5
1	5.01	1.88	3.38	10.3
2	4.55	2.00	3.42	10.2
3	4.54	1.99	3.38	10.3
4	3.71	2.19	3.22	10.4
5	3.90	2.10	3.16	10.5
6	3.87	2.12	3.19	10.6
7	3.60	2.14	3.02	10.5
8	3.81	2.09	3.06	9.9
Mean	4.29	2.02	3.21	10.4
SD	0.69	0.16	0.15	0.2

Whole and Broken Pellets

No pellets were retained on the 8.00-mm sieve. Pellets that were retained on sieve sizes 6.70, 6.30, and 5.60 mm were considered whole pellets. Those that passed through the sieve sizes 5.60, 3.35, 1.70, and 1.00 mm were considered broken pellets (ASAE Standards, 2003a).

The mass of whole pellets decreased with subsequent transfers, from 82.5% to 49.8% (Fig. 2). This was due to pellet breakage occurring while being transferred from bin 1 to bin 2 and vice versa. As expected, the mass of broken pellets increased with subsequent transfers. The percentage of broken pellets increased from an initial value of 17.5% to 50.2%, equivalent to an average of 4% increase with each transfer. The observation of constant increase in breakage during the first four transfers was similar to that of Foster and Holman (1973), and Martin and Stephens (1977).

The least-squares best-fit line showed a second-order polynomial relationship between number of transfers and broken pellets or whole pellets, with a coefficient of determination, R^2 = 0.96. This relationship was expected because the weaker pellets break easily and faster during the earlier transfers.

Zatari et al. (1990) indicated that broilers fed 75% whole pellets and 25% broken pellets, as compared with 25% whole pellets and 75% broken pellets, had better feed efficiency and higher body weight. For this study, a percentage of whole pellets of 75% or better was achieved up to Transfer 1 only; the percentage of whole pellets decreased to approximately 50% as the final transfer was reached. Amornthewaphat et al. (1999) found a linear decrease in efficiency of growth of finishing pigs as fines or broken pellets was increased from 0% (7% greater gain/feed than meal control) to 50% (2% greater gain/feed than meal control). In this study, 50% fines was achieved after Transfer 8.

Moisture Content, Drop Height and Breakage

Foster and Holman (1973) enumerated the variables involved in corn breakage caused by commercial handling, namely: free fall height, impact surface, and corn moisture content and temperature. Corn that dropped from a height of 12 m onto corn in the commercial handling study caused 4.3% breakage for corn with 12.6% moisture at -3.8°C, and 0.25% breakage for

corn with 15.2% moisture at -5.0°C. It was also observed that breakage of corn handled decreased at higher grain temperatures.

Martin and Stephens (1977) observed breakage within the range reported by Foster and Holman (1973). The corn had a fall similar to the average 16-m free fall in bins 1 and 2. It had a moisture content of about 13% and a temperature of 11°C. A constant increase in breakage during four repeated transfers was also observed, in line with the observation of Foster and Holman (1973).

By comparison, the pellets in this study had a similar free fall in bins 1 and 2 at an average height of 16 m. The mean moisture content was about 10.4% wb. Mean moisture content of each transfer was not significantly different with each other (p>0.05). The pellet's mean moisture content was not within the range of moisture content values mentioned by Foster and Holman (1973). The average percentage increase in breakage was 4.0% with each transfer, however, which was within their observed range of breakage values.

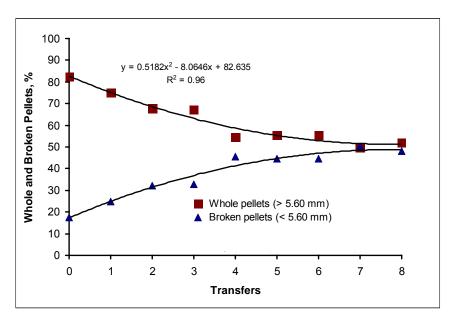


Figure 2. Whole and broken pellets (in percentage of total mass of pellets) from each transfer.

Pellet Durability Index

The initial PDI was 92.8% (SD=1.2%). For Transfers 1, 4, and 7, the PDI values were 92.0% (SD=1.5%), 93.3% (SD=0.2%), and 93.4% (SD=2.0%), respectively. The PDI values increased only slightly and were not significantly different (p>0.05).

Dozier (2001) reported that minimum PDI values differ for different meat birds: 96% for ducks, 90% for turkeys, and 80% for broilers. Hanrahan (1984) reported no difference in finishing pig performance between pigs restrictedly fed a 69% or 62% PDI pellet.

Aarseth (2004) who compared three types of feed pellets: FF30, FE, and KN, indicated that the pellet with highest bulk density (BD) was also the least susceptible to attrition in the Holmen pellet tester. The BDs of the FE and FF30 tested for 120 s in the Holmen tester were 641 and 664 kg/m 3 and the PDIs were 92% and 96%, respectively. The KN pellet, which was tested for 30 s, had BD = 623 kg/m 3 and PDI = 94%. The feed pellets in this study had a BD of 644 kg/m 3 and initial PDI of 92.8%, which is comparable to FE in Aarseth's study. It should be

noted, however, that the Holmen tester seemed to be harsher than the tumbling box method, and therefore would yield lower PDI values (Winowiski, 1998).

Pellet Dust

The standard t-test showed that the mean percentage of tailing dust (0.069%) of the pellet mass) in the eight transfers of this study (Table 2) was significantly different (p<0.01) than the mean for 20 transfers in Martin and Stephens (1977) (0.088% of corn mass), but comparison with only the first eight transfers of the shelled corn (0.082% of corn mass) did not show a significant difference in mean percentage of tailing dust (p>0.05).

The total mass of fine dust (<125 μ m) did not differ significantly (p>0.05) between Transfers 2 and 3, between Transfers 3, 4, and 5, or between Transfers 6 and 8 (Table 2). A sharp increase was evident in Transfers 6 and 8, and a decrease was noted in Transfer 7. It was not evident what caused Transfer 6 to have this large difference. Transfers 7 and 8 both occurred after the pellets rested in the bin for one week, however, which could have contributed to significantly different results for those transfers.

Table 2. Mean tailing dust and calculated amount of fine dust per transfer.

Transfer		Fine Dust (SD),
	Tailing Dust (% of Total Pellet Mass)	kg/ t of pellets handled
1	0.063	0.312 (±0.0218) ^a
2	0.072	0.343 (±0.0039) ^b
3	0.068	0.333 (±0.0035) bc
4	0.071	0.329 (±0.0057) ^c
5	0.067	0.325 (±0.0022) ^c
6	0.084	0.414 (±0.0169) ^d
7	0.052	0.235 (±0.0026) ^e
8	0.079	0.406 (±0.0134) ^d
Mean	0.069	0.337 (±0.0087)
SD	0.010	0.056 (±0.0076)

Means with same letters are not significantly different at 5% level.

Overall, the fine dust in this study was 50% of the total dust collected; the amount fine dust in Martin and Stephens (1977) for shelled corn was larger (70% of the mass of the dust). This percentage of fine dust in the total pellet dust was significantly different (p<0.01), compared both with the mean of 20 transfers and with the mean of only the first eight transfers of shelled corn.

We observed an increase in the amount of fine dust during the four cycles (eight transfers), as shown in Table 2. Martin and Stephens (1977) stated that they also observed an initial increase in the amount of fine dust emitted in the first four cycles; the amount of fine dust became constant during subsequent transfers.

Correlation Analyses

Apparent GMD decreased significantly as both percentage of broken pellets and percentage of dust increased. For GMD and percentage of broken pellets, the correlation was especially high, r = -0.99 (p<0.01). The rest had weak correlation. Percentage of tailing dust and GMD had r = -0.69 (p<0.05). The GMD and amount of fine dust had r = -0.66 (p=0.05). Percentage of broken pellets and percentage of tailing dust had r = 0.64 (p>0.05). Percentage of broken pellets and amount of fine dust had r = 0.62 (p>0.05).

The high correlation of GMD and percentage of broken pellets was likely because both parameters were strongly affected by forces acting on pellets during transfers that tended to break the pellets into smaller pieces. These forces increased the percentage of broken pellets and decreased the pellet size (GMD).

As GMD decreased, PDI values increased slightly. With the PDI values for the four transfers (Transfers 0, 1, 4, and 7) not being significantly different from each other (p>0.05), however, correlations among PDI and other parameters were also not significant (p>0.05).

Conclusion

Feed pellets made from corn meal were tested for durability and breakage during repeated handling in the research grain elevator. The pellets were transferred alternately between two storage bins, for a total of eight transfers. The following conclusions were drawn from the research:

- 1. Repeated handling did not significantly affect the pellet durability index, which ranged from 92.8% to 93.4%.
- 2. The percentage of broken pellets (< 5.60 mm) increased from an initial value of 17.5% to 50.2% after eight transfers.
- 3. The average mass of dust removed per transfer was 0.069% of the mass of pellets, which was not significantly different than previous tests with shelled corn for eight transfers. Overall, 50% of dust collected was fine dust (≤125μm), which was a smaller percentage than that collected with shelled corn (Martin and Stephens, 1977), indicating that these pellets produced less dust emissions during handling than shelled corn.
- 4. The apparent geometric mean diameter of the sample decreased with repeated transfers. The amount of broken pellets and percentage of tailing dust removed per transfer increased with repeated handling. The GMD and percentage of broken pellets were negatively and highly correlated (r > 0.9). The PDI was not correlated with any of the parameters at $\alpha = 0.05$.

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